UNITED STATES PATENT APPLICATION

INTERFERENCE REDUCTION USING LOW COMPLEXITY ANTENNA ARRAY

INVENTORS

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FIELD OF THE INVENTION

The invention relates generally to communication systems and, more particularly, to interference reduction techniques for use therein.

BACKGROUND OF THE INVENTION

In a cellular communication system, a plurality of wireless base stations are typically used to provide communication services to mobile users within the system. Each base station will often service multiple users within a coverage region or cell associated with the base station. To allow multiple users to share a base station, a multiple access scheme is typically employed. One multiple access technique that is becoming increasingly popular is code division multiple access (CDMA). In a CDMA-based system, a plurality of substantially orthogonal codes (usually taking the form of pseudo-random noise sequences) are used to spread spectrum modulate user signals within the system. Each modulated user signal has an overlapping frequency spectrum with other modulated user signals associated with the base station. However, because the underlying modulation codes are orthogonal, each user signal can be independently demodulated by performing a correlation operation using the appropriate code.

In at least one CDMA-based cellular standard, each of the base stations in a system maintains a pilot channel that continuously transmits a predetermined pilot sequence. These pilot signals may then be utilized by users in the system to perform, for example, channel estimation, handover operations, and/or other functions. Pilots from different base stations are sometimes distinguished by a time offset between individual base stations. Thus, a pilot having a specific time offset (from, for example, an absolute time reference) will be known to have come from a corresponding base station. As can be appreciated, a communication device

operating within a cellular-based system implementing CDMA will often receive overlapping communication signals from a variety of different sources (e.g., other base stations, etc.). These overlapping signals represent interference in the system and can degrade system performance. Any reduction in such interference, therefore,

5   may enhance the quality of the corresponding communication link or increase the capacity of the system. Thus, there is a general need for methods and structures to reduce interference in cellular communication systems.

BRIEF DESCRIPTION OF THE DRAWINGS

10   Fig. 1 is a simplified top view illustrating a cellular communication system that can utilize the principles of the present invention;

Fig. 2 is a block diagram illustrating a receiver system in accordance with an embodiment of the present invention that is capable of achieving reduced interference;

15   Fig. 3 is a block diagram illustrating a receiver system in accordance with another embodiment of the present invention;

Fig. 4 is a flowchart illustrating a method for reducing interference in a communication device in accordance with an embodiment of the present invention; and

20   Fig. 5 is a timing diagram illustrating the timing associated with the method of Fig. 4 in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying

25   drawings that show, by way of illustration, specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. It is to be understood that the various embodiments of the invention, although different, are not necessarily mutually exclusive. For example, a particular feature, structure, or characteristic

described herein in connection with one embodiment may be implemented within other embodiments without departing from the spirit and scope of the invention. In addition, it is to be understood that the location or arrangement of individual elements within each disclosed embodiment may be modified without departing

5 from the spirit and scope of the invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims, appropriately interpreted, along with the full range of equivalents to which the claims are entitled. In the drawings, like numerals refer to the same or similar functionality throughout the several views.

10 The present invention relates to methods and structures for reducing interference within a communication system using a relatively low complexity antenna arrangement. The methods and structures can be used, for example, within a mobile communicator unit (e.g., a cellular telephone, etc.) to reduce the impact of potentially interfering signals. Two or more antenna elements are provided within a

15 communication device, at least one of which has an adjustable weight (e.g., magnitude and/or phase). The weight of the adjustable element(s) is adapted during system operation in a manner that enhances a preselected interference-related quality criterion (e.g., signal to interference and noise ratio (SINR)). The inventive principles can be implemented in a variety of different communication systems and

20 devices and are particularly beneficial for use within cellular-type communication systems implementing CDMA techniques.

Fig. 1 is a simplified top view illustrating a cellular communication system 10 that can utilize the principles of the present invention. As illustrated, the cellular communication system 10 includes a plurality of base stations 12, 14 that are

25 physically distributed within an area. Each of the base stations 12, 14 has a corresponding coverage region or cell 16 within which the base station 12, 14 provides wireless communication services to mobile users. As used herein, the term servicing base station refers to the base station that is presently providing communication services to a particular user. For example, with reference to Fig. 1,

base station 14 is acting as the servicing base station for mobile user 18 who is located within the cell 16 of base station 14. Mobile user 18 will typically receive signals from a number of base stations 12 within the system 10 in addition to the servicing base station 14. As described previously, in a CDMA-based system, the

5 signals received from the various base stations may have overlapping spectrums. As can be appreciated, these overlapping signals can negatively impact the quality of communication within the system 10.

Fig. 2 is a block diagram illustrating a receiver system 20 in accordance with an embodiment of the present invention. As will be described in greater detail, the

10 receiver system 20 is capable of outputting a received signal having reduced interference within a corresponding communication device. In at least one application, the receiver system 20 is implemented within a mobile communication device that is operative within a cellular-based communication system. The mobile communication device can include, for example, a cellular telephone, a pager, a

15 laptop computer or personal digital assistant (PDA) having wireless transceiver functionality, and others. As illustrated, the receiver system 20 includes: first and second antenna elements 22, 24, an adjustable gain unit 26, an adjustable phase unit 28, a combiner 30, a radio frequency (RF) receiver 32, a baseband processor 34, and a gain and phase controller 36. The first and second antenna elements 22, 24 are

20 operative for receiving radio frequency (RF) communication signals from the surrounding environment. The RF communication signals received by the first and second antenna elements 22, 24 may include, for example, signal components from a number of different base stations. The adjustable gain unit 26 and the adjustable phase unit 28 are operative for controllably varying the magnitude and phase,

25 respectively, associated with the first antenna element 22. The combiner 30 combines the output signals of the first and second antenna elements 22, 24 and delivers the combined signal to the RF receiver 32.

The RF receiver 32 processes the combined signal to generate a baseband communication signal. The baseband processor 34 processes the baseband signal to

extract user information associated with a user of the communication device. The baseband processor 34 also delivers information derived from the baseband signal to the gain and phase controller 36. The gain and phase controller 36 uses the information from the baseband processor 34 to generate gain and phase control information for the adjustable gain and phase units 26, 28. The gain and phase control information generated by the gain and phase controller 36 is dynamically adjusted during system operation in a manner that reduces interference within the receiver system 20. In a preferred approach, the gain and phase control information is adjusted to optimize a preselected interference-related quality criterion (e.g., SINR). In this manner, the gain and phase controller 36 can adjust the position of the composite receive beam of the receiver system 20 to favor the servicing base station while avoiding other base stations in the vicinity (particularly those with high powers).

As described above, the outputs of the first and second antenna elements 22, 24 are combined within the combiner 30 before RF processing is performed within the RF receiver 32. Thus, only a single RF path (e.g., one intermediate frequency (IF) section, one analog to digital converter, etc.) needs to be provided within the receiver system 20 even though multiple antenna elements are being used. Conventional phased array principles are relied upon to control the receive beam. Any of a wide variety of different antenna types can be used for the antenna elements 22, 24. For applications within handheld communicators, the antenna elements 22, 24 will preferably be relatively inexpensive structures having a relatively low profile. Some antenna types that may be used include, for example, microstrip patches, dipoles, monopoles, dielectric, printed, inverted F, slots, and others. In at least one embodiment of the invention, two (or more) different types of antenna element are used within a communication device. Also, a better quality antenna element may be used for the non- adjustable antenna element(s) (e.g., second element 24) than for the adjustable element(s) (e.g., first element 22), or vice

versa. The antenna elements within a communication device can have the same or different polarizations.

It should be appreciated that more than two antenna elements can be used in accordance with the present invention as long as at least one of the antenna elements has a variable magnitude and/or phase to allow beam steering to occur. For example, Fig. 3 is a block diagram illustrating a receiver system 40 in accordance with another embodiment of the present invention. As illustrated, system 40 includes first and second antenna elements 22, 24 as described in the previous embodiment. System 40 also includes one or more additional antenna elements 42 each having a corresponding adjustable gain unit 44 and adjustable phase unit 46. During system operation, the gain and phase controller 36 delivers gain and phase control information to the adjustable gain and phase units associated with each of the adjustable antenna elements 22, 42. As described above, the gain and phase control information generated by the gain and phase controller 36 is dynamically adjusted during system operation in a manner that reduces interference within the system 40. Any number of adjustable antenna elements may be used.

Fig. 4 is a flowchart illustrating a method for reducing interference in a communication device in accordance with an embodiment of the present invention. The method may be practiced in connection with, for example, the receiver system 20 of Fig. 2. The method will be described in conjunction with the timing diagram of Fig. 5 which illustrates a number of successive processing cycles (i.e., cycles starting at n- 1)T, nT, and (n+1)T, respectively) within the digital system. The cycle time T may be optimized based on, for example, the current Doppler rate (i.e., the mobile speed), which can change in real time during normal system operation. With reference to Fig. 4, a communication device is first provided that includes first and second antenna elements (block 50). The first antenna element has an adjustable weight (magnitude and/or phase). The outputs of the first and second antenna elements are combined within a combiner. At the beginning of a processing cycle (e.g., at nT in Fig. 5), a predetermined weight w (which may be complex) is applied

to the first antenna element and held for τ seconds (block 52). As will be described in greater detail, this predetermined weight will allow channel responses to be estimated for channels between each of a plurality of base stations of interest and each individual antenna element of the communication device. In at least one

5   approach, the predetermined weight will set the magnitude of the first antenna element to zero, effectively removing the first antenna element from the system for duration τ. However, other predetermined weights can also be used. The same predetermined weight may be applied to the first antenna element during each successive cycle or different predetermined weights may be applied in successive

10   cycles.

During duration τ of the present processing cycle (see Fig. 5), the combined channel response of the first and second antenna elements is estimated for each of the base stations of interest (block 54). The combined channel response is the response of the first and second antenna elements after combination within the

15   combiner. The combined channel response for a particular base station is estimated using the pilot tone received from that base station. Methods for estimating a channel response using a received pilot tone are known. The base stations of interest may be selected in a variety of different ways. If adequate resources are available, all of the base stations within the system may be treated as base stations

20   of interest. In another approach, the N highest power base stations in the system (i.e., the base stations having the strongest receive signals within the communication device) are selected as the base stations of interest (where N is a positive integer). A list of the highest power base stations is often maintained within a communication device for use in performing handoff operations. In still another approach, all base

25   stations having a detected power level exceeding a predetermined threshold level are used as the base stations of interest. In still another approach, the N strongest paths from different base stations are considered and therefore define the base stations of interest. As will be apparent to persons of skill in the art, other techniques for identifying base stations of interest may also be used.

After the combined channel responses have been estimated, the channel responses associated with the individual antenna elements are calculated for the base stations of interest (block 56). In at least one approach, information associated with a previous processing cycle (e.g., the cycle from (n-1)T to nT in Fig. 5) is used to calculate the channel responses associated with the individual antenna elements for the present processing cycle (e.g., the cycle from nT to (n+1)T in Fig. 5) by solving two equations in two unknowns. The following two vector equations describe the relationship between the combined channel responses and the individual antenna channel responses at time [nT, nT+τ] and [(n-1)T+τ , nT) respectively:

$$\begin{cases} h_k(t) = \widetilde{W}C_k(t) & t \in [nT, nT + \tau] \\ h_k(t) = W_{(n-1)T}C_k(t) & t \in [(n-1)T + \tau, nT) \end{cases}$$

where $h_k(t)$ is the combined channel response at time t associated with base station k (where k=0 corresponds to the serving base station) which may be continuously estimated and tracked using well known estimation techniques. $C_k(t)$ is the matrix channel response from base station k to each of the antennas at time t. The element $\{C_k(t)\}_{ij}$ of the matrix $C_k(t)$ represents the channel response of the j'th path at the i'th antenna element. The j index will often be no larger than the maximum number of fingers in the corresponding rake receiver. The vector $W_{(n-1)T} = (w, 1)$ is the gain of the antennas during the former time period [(n-1)T+τ , nT). The vector $\widetilde{W}$ represents the vector gain of the antennas using the predetermined weight w that is applied at time t=nT and held for period [nT, nT+τ]. The combined channel response $h_k(t)$ for time [nT, nT+τ] has been estimated above (for each base station of interest k). The values of $h_k(t)$ and W for the previous time period [(n-1)T, nT] are known. The vector W that is used for the [(n-1)T+τ , nT] time period includes the new weight that was generated at time (n-1)T+τ (see Fig. 5) and not the predetermined weight. The individual channels ($C_k(t)$) at the end of the (n-1)T

period are equal to the ones at the beginning of period nT, whereas the combined channel response ($h_k(t)$) is different due to the different weight vectors ($\tilde{W}$ as opposed to $W_{(n-1)T}$). In order to determine the channel responses associated with the individual antenna elements, the two vector equations are solved for two unknowns

5 at t=nT; namely, the channel responses at each of the antenna elements $C_k(nT)$. This is done for each path of each base station of interest. Similar solutions can be performed for systems using three or more antenna elements.

Using well known estimation techniques, the transmitted power of each of the base stations of interest (P_k), the pilot power of the servicing base station (P_d),

10 and the white noise variance vector $\sigma = (\sigma_1, \sigma_2)$ at the antennas are estimated (block 58). A new weight for the first antenna element is then calculated that maximizes a predetermined quality criterion (block 60). In one embodiment, the signal to interference and noise ratio (SINR) is used as the quality criterion. In this embodiment, a new weight is determined that maximizes the following equation:

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$$SINR = \frac{P_d\left|\left(WC_0\right)*\left(WC_0\right)^H\right|^2}{\frac{1}{SF}P_0 G\left(\left(WC_0\right)^H*\left(WC_0\right) - diag\left(\left(WC_0\right)^H*\left(WC_0\right)\right)\right) + \frac{1}{SF}\sum_{k=1}^{N} P_k G\left(\left(WC_0\right)^H*\left(WC_1\right)\right) + \frac{1}{SF}\left(WC_0\right)\left(WC_0\right)^H\left(\left(\sigma W^T\right)\left(\sigma W^T\right)^H\right)}$$

where SF is the pilot spreading factor, the operation G(A) returns the sum of the absolute square of the elements of matrix A, X^H is the conjugate transpose of matrix X, and X^T is the normal transpose of matrix X. It should be appreciated that the last

20 term in the denominator of the above equation relates to white Gaussian noise in the channel and in some cases can be ignored. Other quality criteria that may be used include, for example, the mean square error (MSE) of the pilot signal, the bit error rate (BER) at the output of the rake receiver, and others. In one approach, the new

25 weight is selected from a finite set of predetermined weights. By using a finite set of possible weights, overall system complexity can be reduced.

After the new weight w has been determined, the weight is applied to the first antenna element for the remainder of the present processing cycle (i.e., for the next T-τ seconds, as illustrated in Fig. 5) (block 62). The above described process is then repeated for subsequent processing cycles (block 64). In this manner, the receive beam of the communication device is continuously adjusted to achieve a reduced level of interference within the communication device. The above described method may be modified for use in systems having more than two antenna elements (e.g., receiver system 40 of Fig. 3).

Although the present invention has been described in conjunction with certain embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention as those skilled in the art readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and the appended claims.